Assessment of the Value of SSMIS for Data Assimilation in the Middle Atmosphere

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Objectives

Develop a high-resolution global model (NOGAPS-ALPHA*) of the atmosphere from the ground to the lower thermosphere (~130 km), integrating state-of-the-art developments in high-altitude weather and climate monitoring.

Extend the data assimilation system (NAVDAS*) to 100 km by integrating additional satellite sensors, and modifying the background error structure functions (correlations) and error variances.

*NOGAPS: Navy Operational Global Atmospheric Prediction System
*NOGAPS-ALPHA: NOGAPS Advanced Level Physics, High Altitude
*NAVDAS: NRL Atmospheric Variational Data Assimilation System

Data Assimilation

In an operational NWP model, **data assimilation** is used to incorporate real-world observations. The goal of data assimilation is to give the best estimate (**analysis**) of atmospheric state for the NWP initial conditions by combining forecast model fields (**background**) and **observations**.

We minimize a penalty function:

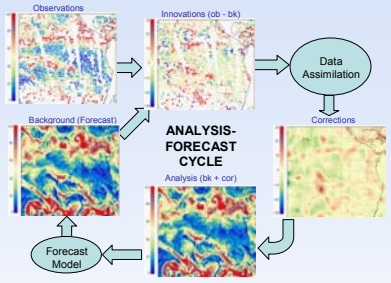
$$J(x) = \underbrace{(y-\mathcal{H}(x))^T}_{\text{observations}} \underbrace{R^{-1}}_{\substack{\text{observation}\\ \text{error covariance}}} (y-\mathcal{H}(x)) + \underbrace{(x-x_b)^T}_{\text{background}} \underbrace{P_b^{-1}}_{\substack{\text{background}\\ \text{error covariance}}} (x-x_b)$$

(forward operator; analysis variables)

This is an optimal estimation problem constrained by the error covariance matrices of the background and the observations. The solution is:

$$\underbrace{\hat{x}_a - \hat{x}_b}_{\text{correction}} = \mathbf{P_b H}^T \left(\mathbf{H P_b H}^T + \mathbf{R}\right)^{-1} \underbrace{\left(\hat{y} - \mathcal{H}(\hat{x})\right)}_{\text{innovation}}$$

(Jacobian)



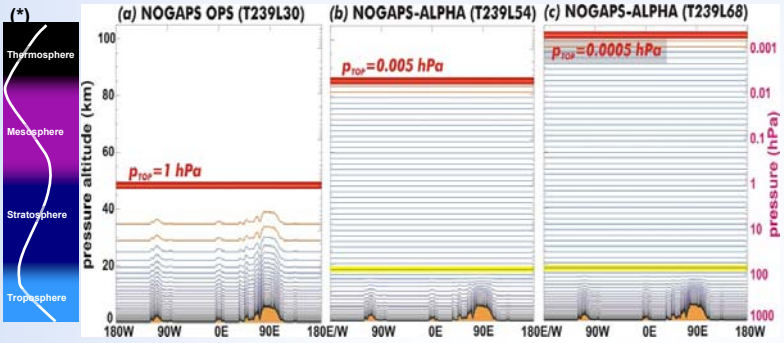
Instruments

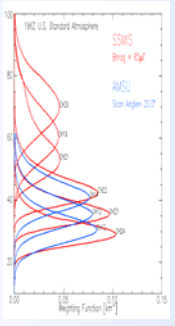
Temperature sounders typically used at NWP centers include microwave sounders such as NOAA AMSU and infrared sounders such as NASA AQUA AIRS, and NOAA HIRS. These are effective up to about 1 mb (40 km). The recently launched EUMETSAT METOP satellite has AMSU, HIRS and IASI (infrared) sensors.

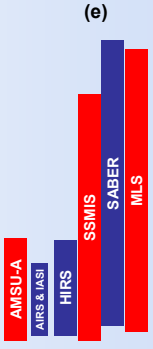
Other satellite instruments that measure the temperature of the stratosphere and mesosphere include:

- DMSP SSMIS includes Upper Air Sounding (UAS) channels in the 60 GHz oxygen absorption band which extend the range of downward-viewing microwave radiometers to around 85 km altitude.
- NASA's IR and microwave limb sounders, SABER and MLS, sample the atmosphere from about 10 km to 100 km with high vertical resolution (but poorer horizontal resolution).

(*) Typical temperature profile of the atmosphere. (a) Plot of operational NOGAPS (L30) sigma levels. (b) NOGAPS-ALPHA L54 hybrid levels. (c) L68 hybrid levels. (d) Weighting functions of highest-peaking channels on AMSU-A and SSMIS. (e) Approximate altitude range of some satellite temperature-sounding instruments.



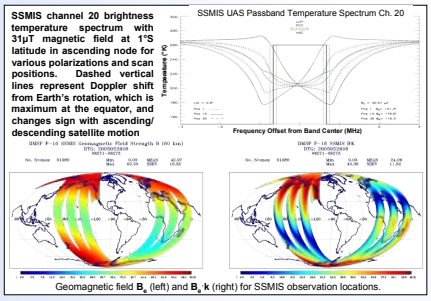




Zeeman Effect

- Interaction of oxygen molecule absorption spectrum with geomagnetic field (B_e) leads to Zeeman splitting of absorption lines.
- Important for upper atmosphere remote sensing (above ~30 km) within the microwave oxygen spectrum
- Leads to a shift in peaks of the weighting functions depending on B_e
- Upper atmosphere radiative transfer (RT) calculations require anisotropic polarized radiative transfer to resolve Zeeman splitting due to the interactions of the directional geomagnetic field and the permanent dipole moment of the O_2 molecule.

SSMIS channel 20 brightness temperature spectrum with 31μT magnetic field at 1°S latitude in ascending node for various polarizations and scan positions. Dashed vertical lines represent Doppler shift from Earth's rotation, which is maximum at the equator, and changes sign with ascending/descending satellite motion



Geomagnetic field $\mathbf{B}_e$ (left) and $\mathbf{B}_e \cdot \mathbf{k}$ (right) for SSMIS observation locations.

Upper Atmosphere Radiative Transfer (RT) Models

Data assimilation requires both the forward RT model and its adjoint (Jacobian).

Forward RT model computes brightness temperatures from the model background model fields.

The Jacobian maps differences between the observed and background brightness temperatures (i.e., innovation) back to changes in the background temperature profiles (i.e., the correction).

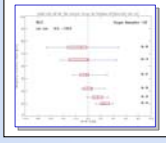
Operational data assimilation requires a fast and accurate RT model and adjoint -- 6 hours of satellite radiances in under 5 minutes

NRL line-by-line model is far too slow. We plan to use the Community Radiative Transfer Model (CRTM), developed by the Joint Center for Satellite Data Assimilation (JCSDA).

Results

LBL RT model comparison

- Run line-by-line (LBL) forward model on merged ECMWF/Lidar/COSPAR profiles at Table Mountain, CA and Mauna Loa, HI.
- Compare to observed SSMIS T_Bs for all scenes within matchup radius (several SSMIS observations for one profile).
- Actual filter shapes (100 point NRL data)
- Use SSMIS Observed $|\mathbf{B}_e|$, $\mathbf{B}_e \cdot \mathbf{k}$ and θ_B for each scene location

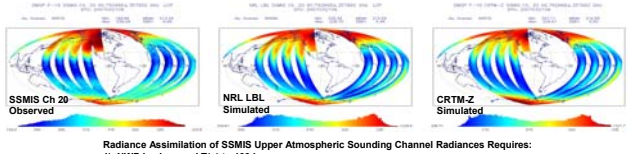


Observed minus background T_B distribution for channels 19-24. Boxes show the mean and one standard deviation about the mean. Whiskers show range of data.

Forward Model Intercomparison (LBL vs. CRTM-Zeeman)

- Global Simulations using ECMWF and CIRA-86 Climatology
  - ECMWF Temperature Analyses extend to 0.01 hPa (~ 80 km)
  - CIRA-86 Climatology extends T(p,z) to 0.001 hPa (~ 95 km)
- NRL LBL RTM vs Fast Model with Zeeman Effects Included
  - CRTM-Z (Yong Han, NOAA/JCSDA) compares to LBL **within 1.0 K**
  - NRL LBL -- 6 Hours of CPU time per SSMIS rev
  - CRTM-Z -- under 30 seconds per SSMIS rev
- Global Simulations and Radiance Assimilation of SSMIS UAS data now possible with CRTM-Z
- ECMWF Background Temperature has an uncertainty at 0.1 – 0.01 hPa of ~5 - 10°K.
- SSMIS UAS Radiance data have potential to improve current Upper Stratospheric and Mesospheric temperature analyses

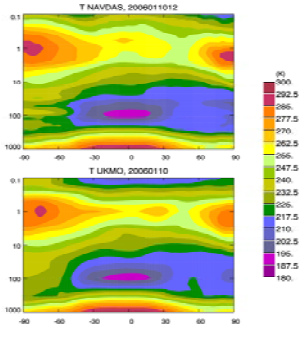
Results (con't)



Radiance Assimilation of SSMIS Upper Atmospheric Sounding Channel Radiances Requires:
1) NWP background T(p) to 100 km
2) A Fast Radiative Transfer Model including Zeeman Splitting effects

Preliminary Microwave Limb Sounder (MLS) Assimilation Results

NAVDAS and UKMO Zonal Mean Temperature Jan 10, 2006, 12UT



- NAVDAS (analysis) top at 0.1 hPa
- Assimilated conventional observations
  - including radiosondes and pibals, satellite tropospheric and surface winds and total precipitable water, surface land and ship, aircraft winds
- NOAA AMSU-A, channels 4-10
- MLS temperature retrievals from 31.6 to 0.1 hPa.
- NOGAPS-ALPHA T79L60 (model top 0.005 hPa)
- Assimilation run began 20 Dec 2005;
- Analysis is for 10 Jan 2006 (30 days of assimilation)

UKMO: Met Office Stratospheric Assimilation Data from the British Atmospheric Data Center

Upper atmosphere version of NAVDAS with NOGAPS-ALHPA is in good qualitative agreement with the Met Office analysis.

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Future Work

- Further validation of JCSDA CRTM with Zeeman effect to determine the polarization that best fits the SSMIS data.
- Integrate MLS and SBUV/2 ozone assimilation system with NOGAPS-ALPHA.
- Validate SABER temperature, and MLS temperature and water vapor assimilation with NAVDAS.
- Develop and validate NAVDAS assimilation of AIRS, HIRS, IASI and SSMIS radiance assimilation for upper atmospheric analysis and modeling.